SOIL MICROMORPHOLOGY AND SOIL FAUNA: PROBLEMS AND IMPORTANCE

S. Pawluk
Department of Soil Science
University of Alberta
Edmonton, Alberta T6G 2E3
CANADA

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ABSTRACT

Surface soil layers were viewed microscopically along a pedogenic gradient from the northern Arctic to the southern Parklands within the Interior Plains region and westward to the Alpine and Interior Grasslands of British Columbia. In all instances it appears that soil animals play a major role in structural development although the relationship between humus form, synecology and microfabrics remains vague. Among all animals present microarthropod influences are the most ubiquitous in their influence upon soil microstructures and humus formation. Larger animals are more prominent in the Parkland region and appear to play a major role in regulating humus form; while moder humus form is most evident in the cold northern regions of the Arctic, proto-mull appears to be more characteristic of the warmer Parkland environment. Humus form of the Interior Grasslands is generally characterized by moder and little is evident for the action of larger soil animals upon development of soil microstructure; the reason for this is not clearly understood.

RÉSUMÉ

Les horizons supérieurs des sols ont été examinés au microscope le long d'un gradient pédogénique s'étendant du nord de l'Arctique jusqu'au Parklands des Plaines au sud et à l'ouest jusqu'aux Prairies alpines et des plateaux intérieurs de la Colombie-Britannique. Dans tous les cas, il semble que la faune du sol joue un rôle primordial dans le développement de l'aspect structural, même si les rapports entre la forme de l'humus, la microtexture et la synécologie sont encore vagues. De toute la faune du sol, les microarthropodes contribuent le plus à la microstructure des sols et à la formation de lhumus. Les éléments plus gros de la faune sont plus communs dans la region des Parklands et semblent y jouer un rôle primordial dans la détermination de la forme d'humus. La forme moder d'humus est plus répandue dans les régions froides de l'Arctique alors que le proto-mull semble caractériser davantage l'environnement plus chaud des Parklands. La forme d'humus des Prairies de l'intérieur est généralement cractérisée par du moder, et, pour des raisons que l'on s'explique encore mal, on y observe peu d'évidence indiqant l'action des éléments plus gros de la faune du sol sur le développement de la microstructure.

INTRODUCTION

The Problem

The principal problem facing those who work in micromorphology and formation of soil microstructure in relation to faunal activity, is the general lack of clarity as to the importance of soil animals in initiating and maintaining soil fabric rearrangement. Of secondary importance is the need for more precise cataloguing of a specific feature or features that each organism or group of organisms is capable of contributing to the reorganization of soil materials.

Early Research

The importance of soil animals in soil structural development has long been recognized. Contributions from earthworms have been singled out for special attention by early researchers such as Charles Darwin and P.E. Müller. Kubiena (1953) described forest mull as comprising earthworm casts and their residues and to this he attributed the 'crumb' structure that is so characteristic of these layers. However, as Jacks (1963) accurately pointed out, while it is generally accepted that earthworms create crumb structures of Russian Chernozems, these animals are not generally all that common in North American Prairie soils and crumb mull structures must be produced without earthworms.

Many previous researchers involved in this area of study were convinced other animals were also important contributors to soil reconstruction at the microscopic level (Kubíková and Rusek, 1976; Zachariae, 1963, 1964; Babel, 1973). They not only emphasized the ecological importance and soil genetic contributions of faunal associations but in some instances were able to assign unique fabric arrangements to manifestations of very specific biological activity. Even in his initial work Dr. Kubiena (1953) insisted upon a firm genetic role for soil organisms in reorganization of soil fabric.

Classification of Soil Microstructure and Faunal Activity

From 1938 to 1970 Dr. Kubiena published several textbooks and many scientific articles in which he clearly set forth his concepts on this subject. His fabric type most closely associated with faunal action was *spongy* microfabric. Spongy microfabrics were defined as consisting of aggregates bound to each other in a manner that forms a system of interconected voids and cavities. The internal structure of the aggregates generally remains quite porous. Spongy microfabrics are most frequently associated with mull layers common to the A horizons of soils such as those of the Chernozemic and Brown Forest groups and were believed to be derived entirely through the activity of diverse faunal populations, especially earthworms and potworms. This type of fabric arrangement is regarded as superior to all others from an ecological and management standpoint. Kubiena (1938) also paid attention to forms of moder humus. However, because of the non-coherent nature of these materials their classification was considered at the *elementary fabric* level as some variation of the *agglomeratic* related distribution pattern. This approach is understandable since moder humus comprises a loose mixture of partially decomposed plant remains, mineral fragments and numerous droppings of small arthropods.

Kubiena's terminology for classification of biologically generated soil microfabrics provided a basis for further development by other workers. Up to the time of publication of his text on 'Fabric and Mineral Analysis of Soils' in 1964, Brewer had not given particular emphasis to faunal processes as a basis for classification, however, their influences upon the soil were recognized. Fecal pellets were described as a special kind of *pedological feature* and when deposited in a recognizable channel or chamber they comprised the inner material of some varieties of *pedotubules*. Unfilled *channels* and *chambers* have been attributed in some instances to the burrowing action of animals.

Barratt (1964) attempted to clarify some of the confusion that existed in the classification of humus types and humus forms. Subdivisions of forms of mull and mor humus were described micromorphologically. Class divisions were based on the manner in which organic matter was incorporated (material composition) as well as on the organization (arrangement) of material. Terminology for the initial classification reflected terms used for subdivisions of various humus forms. Later Barratt introduced new terminology recognizing reorganization and composition of fine (*-col*) and coarse (*-skel*) materials. The terms *pelleted* and *spongy humical* and *mullicol* most frequently served to distinguish fabrics derived from discrete and welded casts from various soil animals, some of which are capable of intimately incorporating fine mineral components within the humus forms. Fecal pellets were recognized as an important component in all but raw humus forms.

Stoops and Jongerius (1975) also devised a classification based on spatial arrangement of fine and coarse materials. Aggregated materials such as fecal pellets were considered as discrete entities and divided into fine *(f)* or coarse *(c)* material depending upon size. Thus, fabrics comprising discrete fecal pellets all falling into one size group would be classified as *monic* while fecal pellets of finer size arranged in the intergranular spaces of coarse skeletal particles would be classified as *enaulic*. Kinds of materials were recognized by using suitable suffixes as for example recognizable plant fragments as *phyto-*, well decomposed humus as *humo-*, clay minerals as *argio-*, *etc.* As with Barratt's classification, unique kinds of fabrics could be assigned to activity of specific fauna or faunal groups.

Drawing on concepts by previous workers interested in fabrics of soil organic matter, Bal (1973) proposed that major emphasis be placed on the soil organic component in his concept of the *humon*. The humon is defined as "the collection of observable organic bodies in soil which are characterized by specific morphology and spatial arrangement." Excrement or *modexi* and comminuted plant material were considered to be important components of the humon and their specific morphological classification was based on size, shape, composition and distribution. Bal thus proposed a micromorphometric system for identification of fecal casts but one lacking emphasis on mode of origin. As Bal pointed out, characteristics of modexi are not always unique for a single animal species and knowledge of populations is also an essential element required for assignment of mode of origin. This is especially evident when aging of excrement has progressed to the point where individual modexi are no longer recognizable. In some instances the genetic origin of the fabric type may remain in doubt, since similar features may also be formed by non-biological processes. Biochemical substances (Martin, 1946), frost processes (Post and Dreibelbis, 1942; Fox, 1979) and wetting and drying (Russell, 1973) are examples of processes to which granulation of soil material has been attributed in the past. Formation of organo-clay complexes in mull layers has been attributed to biochemical processes active outside of, as well as within, the intestinal tracts of soil animals (Satchell, 1967).

A micromorphological Classification for Western Canadian Soils

Recent investigations of western Canadian soils developed under grassland, tundra and alpine plant communities with a significant component of grass, forbs and shrub species revealed A horizons with strong granulation at the macro and/or micro levels of fabric reorganization. These soils are in various Soil Orders in the 'Canadian System of Soil Classification' but all have well developed Ah horizons. In order to accommodate these fabric arrangements into a suitable micromorphological classification system, Brewer and Pawluk (1975) further developed a scheme published by Stoops and Jungerius (1975) that recognized special related distribution patterns between fine (*f-matrix*) and coarse (*f-member*) material. Brewer (1979) later introduced the concept of *fabric sequences* which allowed grouping of *fabric types* that exhibited unique genetic relationships. In this regard the fabric sequence that best accommodates the granular character of our soils is the *granic* sequence. The granic sequence comprises four fabric types: *granic*, *granoidic*, *granoidic porphyric*, and *porphyric*. The granic fabric type is used for microstructures comprising units that are discrete and unaccommodated. Such an arrangement is commonly associated with discrete fecal pellets. Granic units of fabric partially coalesced or fused at their edges are referred to as granoidic fabric type (Kubiena's spongy fabric). Granoidic fabric types commonly grade to porphyric types i.e. coalesced units become more densely packed, individual units are no longer recognizable and form a vughy or porous groundmass of coherent soil material. Composition of encompassing material is defined through the use of appropriate prefixes: *humi* - well decomposed humus; *mull* - organo-clay complexes of the mull humus form; *phyto* - partially decomposed plant remains; *ortho* - mineral grains; *matri* - soil matrix constituents (largely inorganic). A mull with spongy fabric is thus designated as mullgranoidic fabric type. Since surface soil horizons of many of our most agriculturally productive soils show mixed granular microstructures with a variable degree of coalescence, the granic sequence is an especially useful concept for descriptive purposes and is used throughout the remainder of this discussion.

Objectives

Surface layers of soils, when viewed microscopically along a pedogenic gradient from the northern Arctic to the southern Parklands within the Interior Plains region and westward to the Alpine and Interior Grasslands of British Columbia, reveal interesting ecological and micromorphological relationships. In all samples it appears that soil animals play a major role in structuring and regulating soil microfabric development. Yet, the relationship that exists between humus form, synecology and microfabrics is poorly understood. While no attempt can be made here to fully develop a meaningful understanding of the dynamics, micromorphological features will be presented in an attempt to illustrate some of the resulting features within the soil fabrics and problems related to discerning their genesis will be raised.

OBSERVATIONS ON SOIL MICROSTRUCTURES FOR SURFACE SOIL LAYERS FROM DIFFERENT BIOCLIMATIC REGIONS

Northern Tundra Region (Table 1.1)

Surface soils examined from the ridge area on Devon Island showed comminuted plant material associated with mineral grains and fine (20-50 μm) humigranic units in a granic fabric arrangement. The humigranic units were relatively uniform in size but somewhat irregular in shape. Some were fecal pellets of microarthropods most likely Collembola and some were melanized plant fragments and cellular tissue. Numerous loosely bound fecal pellets of 200 μm size and comprised of smaller fecal pellets, melanized plant materials and silt size skeleton grains were similar to those reported in the literature for Enchytraeidae. Plant material appeared to be darker and more strongly humified in these latter fecal pellets. The composition is an expression of the feeding habit of the larger fauna. Uniformity in size and shape of fecal pellets reflects the limited diversity in faunal population of these soils. The lack of clay mineral constituents in the fecal material at least in part results from the low content in the soil.

Southern Tundra Region (Table 1.2)

Three well drained soils were studied in the southern Tundra region. Humus forms were essentially similar at all three sites. The moder humus form was well developed and comprised a dominance of humified comminuted plant fragments and fecal pellets from various fauna.

The majority of fecal pellets were of 30-50 μm size, irregular in shape and made up of amorphous humic materials. These were believed to be the droppings of Collembola. Larger humic fecal pellets of 200 μm size in the upper layer frequently contained loosely bound fecal pellets of smaller size as well as humified plant fragments. Similar fecal pellets reported in the literature (Kubíková and Rusek, 1976) were considered to be droppings of Enchytraeidae. Well developed humic fecal pellets of 350-600 μm size resembled droppings of Diplopoda. In some instances the larger fecal pellets were either disintegrating or were being destroyed by microarthropods that left their droppings in the voids. Mull-like fecal pellets of 350-400 μm size formed a thin horizonal zone in the lower moder layer. These fecal pellets were generally smooth, lobate and dense, closely resembling those of Diplopoda. The occasional large humus fecal pellets (900 μm) in this zone were similar to those of Diptera larvae or earthworms. Alignment of unassociated coarse mineral fragments suggested incorporation into the humus layer by frost action.

The immediate underlying soil layer appeared to be a 'proto' mull or mull-like moder. Some smaller mullgranic units of 50-90 μm size strongly resembled Collembola fecal pellets although others appeared smoother and more rounded. Fecal pellets of Enchytraeidae were also very common in this layer. Strong coalescence made it difficult to discern the original nature of most units. Units in the underlying layer became much larger and made up of loosely packed mullgranic material 450-500 μm in size with smaller units of 40-200 μm size in the voids. The smaller units were fecal pellets of Collembola and Enchytraeidae. Origin of the larger units was difficult to discern. In some cases smaller fecal pellets were observed within the larger units. This probably reflects microarthropods feeding on the larger units. The well-rounded moderately accommodated weak mull-like granoidic units in the A(B) were relatively large (1-2 mm) and their origin is unknown. The relatively high amounts of amorphous material found in the fine fraction suggests possible binding associated with freeze-thaw processes.

Forest-Tundra Transition Region (Table 1.3)

The raw soil humus of the lower leaf mat contained a high percentage of partially decomposed comminuted plant fragments together with small (50-90 μm) cylindrical humic fecal pellets most likely of Collembola. There were zones in which the larger fecal pellets (120-200 μm) of Enchytraeidae were concentrated. The underlying forms of moder humus contained an abundance of humic fecal pellets of 50-200 μm size that probably at least in part reflected the activity of Collembola and to a greater extent Enchytraeidae. Lesser amounts of partially decomposed comminuted plant fragments as well as occasional large (850 μm) fecal pellets likely of Diptera larvae were also evident. Humus fecal pellets of 400-600 μm size, that were smooth and usually quite dense, were probably casts of Diplopoda. The Ah horizon had a mull-like fabric arrangement comprised of coalesced fecal pellets dominantly 50-90 μm size and somewhat lesser amounts of units 180-240 μm in size. The units were usually relatively compact mull-like material, smooth in form and frequently lobate or round. However, some units had characteristics of fecal pellets of Collembola and Enchytraeidae (Rusek, 1974) and they were the most likely contributors to this fabric type. Occasional larger units present (350-600 μm) were probably fecal pellets of Diplopoda. Fecal pellets of Collembola were also observed in aggrotubules.

Boreal Forest Region (Table 1.4)

The form of upper moder humus within the organic layer comprised partially decomposed plant fragments and fecal pellets of variable size. Fecal pellets (25 μm) of Acari were associated with decomposing plant fragments. Most fecal pellets were relatively uniform, fairly smooth in outline and of 90-125 μm size. There were also zones of units 50-60 μm in size. The variation in size distribution between zones of fabric may reflect the presence of different species of Collembola. Relatively few irregular shaped, loosely structured units of 125-250 μm size probably were Enchytraeidae droppings while larger units of 600-750 μm size were likely produced by Diptera larvae or small earthworms. Rare large earthworm casts (1.8 mm) were found at the mineral surface contact. Fungal hyphae were abundant throughout the humus layer. This layer showed sharp demarcation from the underlying mineral soil. Mixing of organic and mineral material is minimal and likely reflects the general lack of larger fauna in the population.

Transition Aspen Parkland Boreal Forest Region (Table 1.5)

Forms of moder humus contained an abundance of fecal pellets of highly variable size and shape ranging from 35 to 950 μm in size as well as variable admixtures of partly decomposed plant fragments and few mineral grain f-members. Humic fecal pellets, irregular in shape and of 30-50 μm size, dominated, probably reflecting the presence of Collembola. Many well rounded and lobate units of similar size were likely droppings of Acari. There were zones of concentration of smooth round fecal pellets of 90-125 μm size that strongly resembled major units believed to be dropping of other species of Collembola in many of the northern soils. Other animal origin cannot be discounted, for example because of their similarity to droppings reported for Isopoda (Kubíkoǘ and Rusek, 1976). There was a significant volume of smooth, loosely bound fecal pellets of 350-600 μm size that comprised both humus and mull in the upper layer and mull in the lower layer. These appear to be droppings of Diplopoda. A few large (940 μm) fecal pellets of Diptera and/or small earthworms were also present. The lower H layer was made up of partially coalesced fecal pellets dominantly 25 to 40 μm in size but also contained a significant amount of fecal material in the 120 to 180 μm size range. A lesser amount of fecal material 400-600 μm in size was also present. Most fecal material showed evidence of breakdown that probably reflected aging of collected fecal casts from animals similar to that active in the upper layer. The 'zone of mixing' that intergrades to the Ah had a greater dominance of mull fecal pellets of 200-550 μm size typical of that for Diplopoda. Fine mull fecal pellets of 90-125 μm size, very similar in structure to the humic units of the H layer were also evident.

The Ah layer had greater dominance of larger fecal pellets of 600-750 μm size. In most samples these fecal pellets comprised closely packed smaller units of 45 μm size some of which were made up entirely of humus and others of mull-like material. However a minor portion of the larger units frequently contained mineral matrix material brought up from the lower solum. These fecal pellets closely resembled those of Diplopoda and it appears that they may have played a very significant role in mixing organic and mineral materials in these soils. Large earthworm fecal pellets were relatively rare, however small earthworm casts maybe confused with those attributed to Diplopoda. Observed banded fabric reflects freeze-thaw processes but whether these same processes contribute to formation of well developed microstructural units is as yet uncertain.

Prairie Parkland Region (Table 1.6)

Humigranic and mullgranic units within fabrics of the Ah horizon were largely fecal pellets varying in size from 30 μm to 2 mm. Most of the finer (30-45 μm) fecal pellets probably reflected the presence of Acari and Collembola. Largely humic in composition, they were concentrated in the upper zones of the horizon. Some humigranic units were also melanized plant fragments. The larger mullgranic units (350-750 μm) were diverse in size and degree of compaction and probably reflected the presence of a wide variety of fauna including Diplopoda, Enchytraeidae, Isopoda, small earthworms and Diptera larvae. Contributions from large earthworms (1-2 mm) were much less common and frequently consisted of matrix material from underlying horizons. While the humus form was generally mull-like, the presence of diverse, discrete, poorly homogenized units of soil material suggests an immature or 'proto' stage of mull development.

Alpine Region (Table 1.7)

Humigranic units in the moder layer appeared to be largely fecal pellets of Enchytraeidae and microarthropods with a signficiant component of melanized comminuted plant fragments. Very few large fecal pellets (450-550 μm), likely those of Diplopoda, were evident as well. The Ah showed an increase in dominance of weak mull units of 20-400 μm size that at least in part reflected the activity of Collembola, Acari, and Enchytraeidae. Diplopoda were likely responsible for the very rare large fecal pellets of 600 μm size. Well rounded compact fecal pellets of 90-125 μm size were commonly present. While their origin is doubtful these casts may be formed by specific species of Collembola. Biological influence at depth was more difficult to discern because of the presence of orthogranic units of similar structure that reflected the presence of amorphous constituents such as perlite and volcanic glass. The lack of well developed mull probably reflects the low clay content.

Intermontane Prairie Region (Table 1.8)

The mull-like moder Ah comprised at least in part an abundance of fecal pellets of microarthropods (35 μm), few Enchytraeidae (90-200 μm) and very few Diplopoda (450-600 μm). As with most other soils dense, smooth droppings of 90-125 μm size were commonly present. All fecal material appeared humic in composition under low magnification. Plant fragments frequently had Acari fecal pellets within their decomposing structure. Frequently mineral grains were observed to have organic cutans that probably resulted from deposition of relatively mobile humic substances by wetting and drying and/or freezing and thawing processes. Clay content was low and relatively ineffective in stabilizing humic material.

CONCLUSIONS

All soils from the Northern Tundra to the Parkland regions had microfabrics of humus-rich layers that were considerably modified through faunal activity. The animals acted in several ways. They were responsible for comminution of plant fragments and reorganization of humic and fine mineral material into discrete microstructural units. In some instances their ingestion appeared to enhance mull fabric development through formation of organo-clay complexes. Their channels modified soil porosity and often remained filled with fecal material as pedotubules.

Among all the fauna present microarthropods appeared to be most ubiquitous in their influences upon soil microstructures. Fecal pellets of Acari were usually associated with partially decomposed plant fragments but those of Collembola appeared to be more broadly distributed and of much greater abundance. Fecal pellets of Collembola were found at all sites and dominated in the moder humus forms of the northern Tundra region and Intermontane prairie. In mineral soils collembolan fecal pellets usually occupied voids or old root channels and consisted of enclosing soil material which may have been humus, mull or mineral matrix varying with the niche they occupied. Enchytraeidae were also widely distributed geographically and not all of their fecal pellets were distinguishable from those of Collembola (Hale, 1967). They contributed significantly to fabrics of Alpine, Parkland and Forest-Parkland transition regions. Along with fecal pellets of other larger animals such as Diplopoda and larvae, Enchytraeidae also contributed significantly to the formation of mull fabrics found in the upper soil layers. Earthworms did not appear to play as dominant a role in mull formation in these soils as they do elsewhere (Kubiena, 1953), even though small earthworms are plentiful in some Parkland soils. In some samples it is difficult to distinguish between casts of small earthworms and Diplopoda. Fecal pellets of Collembola and larger animals incorporated organic and mineral constituents that vary in dominance with the degree of soil mixing. Fecal pellets were observed to comprise pure humus, pure mineral matrix as well as mull at different stages of formation. No organisms appeared to be capable of producing mull through a single ingestion. Rather, large animals appeared to feed on fecal pellets of smaller animals which in turn, ingested fecal material of the larger animals. At each stage the fecal material served as substrate for the growth of microorganisms that were being harvested. Repeated turnover of humus and mineral matrix material by the faunal community appeared to enhance the rate of stable mull formation. Thus the synecology within the various soil systems may be more important than individual species numbers in determining the degree of and rate of mull formation.

It was difficult to assign humus types to the majority of the observed soils since various humus forms were identified in each of the pedons albeit in different proportions. The observed upper organic-rich layers at all sites have the properties described for moder (Kubiena, 1953) humus form. However, a thin well developed mull humus layer was observed in the Southern Tundra and Forest-Tundra Transition region. The Alpine and Montane Prairie sites had moder humus forms although very weak mull fabric i.e. organo-clay complexing, was evident especially in some of the larger fecal pellets. The lower humus layer of the Parkland-Boreal Forest Transition soil had a humus form made up entirely of coalescing humic fecal pellets ranging in size from 30-200 μm and had a mull-like arrangement i.e. a mull-like moder (Kubiena, 1953) fabric. On the other hand, fecal pellets of variable size and largely comprising mull material were present in association with mineral grains and partly decomposed plant fragments as discrete units in moder-like arrangement in the upper Ah of the Parkland soil. This humus-form has also been referred to as mull-like moder (Barratt, 1964) but may best be regarded as a 'proto' mull formation since the soil materials were not completely homogenized.

The most serious problem we have in describing our soils arises from the need to assign a genetic origin for the various fabric sequences. Observed fabrics for upper mineral layers of Tundra soils strongly suggests that mull fabric arrangement (Kubiena's spongy fabric) can arise from processes other than faunal activity such as freezing and thawing. How significant these contributions are to maintaining the tilth of our soils is largely unknown. A better understanding of synecological and soil microfabric relationships is also required if we are to take maximum advantage of the natural processes within the soil ecosystem to sustain the productivity of the resource base of our land.

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Table 1. Site Characteristics and Surface Soil Micromorphological Features in some Selected Western and Northern Canadian Soils.

1. Northern Tundra Region

Location:	Truelove Lowlands, Devon Island
Landform:	a) Gravelly beach ridge deposits b) well drained soils on ridge top
Vegetation:	*Dryas integrefolia* and *Saxifrage oppposítefolia* are dominant with some lichens on top of hummocks.
Soil Structure:	Surface layer is an Ahk horizon 10 cm thick with characteristics of a moder humus form. The layer is black (10YR2/1, m) in color and loamy sand in texture. The soil lacks structure and is very friable. Very fine and fine roots are plentiful. The soil material is base saturated with pH 7.2. Organic matter content is 9 percent. The surface layer is underlain by a Bkj and Ck horizon. (For full description see Pawluk and Brewer, 1975a).
Classification:	Orthic Static Brunisol.
Microstructure of Surface Layer:	The moder Ahk horizon has dominantly an ortho-humi-phytogranic fabric near the surface that grades to an ortho-humigranic fabric with depth (Fig. 1a). Humigranic units range from 20-80 μm in size and are irregular in shape (Fig. 1b). Some loosely bound units of 200 μm size that comprise fine humigranic, orthogranic and phytogranic units are also evident (Fig. 1c). Some spores and limestone nodules are present. Matrix is low in clay size mineral components most of which is calcitic in nature.

2. Southern Tundra Region

Location:	Tuktoyaktuk, N.W.T.
Landform:	a) Hummocks of slumped till developed on thermokarst knoll. b) Well drained soil in midslope position.
Vegetation:	*Betula glandulosa* and *Salix arctica* with a dominance of feather-mosses and lichens as ground cover.
Soil Structure:	The soil has a 2 cm thick root mat of raw humus with nonvascular plants overlying a 7 cm thick humus layer. The upper moder humus form is somewhat fibrous and matted comprising both semi-decomposed and decomposed plant material. The underlying 3 cm layer has a mull-like moder humus form. The underlying 10 cm thick A(B) horizon is dark brown (l0YR3/2, m) clay loam, with friable moderate to strong granular structure. Very fine, fine and medium roots are abundant. The soil is slightly acidic (pH 5) and has 7 percent organic matter in the mineral layer. The A(B) has characteristics of weak mull. (For full description see Brewer and Pawluk, 1975; Pawluk and Brewer, 1975b).
Classification:	Brunisolic Turbic Cryosol.

Microstructure of Surface Layer: The upper moder humus form has an ortho-phyto-humigranic fabric (Fig. 2a). The humigranic units range from 30 to 200 μm in size with a strong distribution around 50 μm. Occasional humigranic units of 350 to 600 μm size are randomly distributed. The lower moder layer has a thick band of mullgranic units 350-400 μm size (Fig. 2b) as well as larger humigranic units up to 900 μm size. The underlying mull-like moder has a phyto-mull-humigranoidic fabric type (Fig. 2c) with a dominance of units of 90-100 μm size some of which are well rounded although larger units (200 μm size) are still present. The A(B) horizon has an upper zone of mullgranic and mullgranoidic fabric with mull units showing strong bimodal size distribution in the 40-120 μm and 400-600 μm (Fig. 2d) size ranges. Smaller units frequently occur within the larger units (Fig. 2e). The lower zone of the horizon has a moderately accommodated mull-matrigranic fabric with well rounded units of 1-2 mm size (Fig. 2f). Accommodation and coalescence increase with depth.

3. Forest-Tundra Transition Region

Location: Inuvik, N.W.T.

Landform: a) Glacial till flutings
b) well drained site.

Vegetation: An open canopy of *Picea mariana, P. glauca, Betula papyrifera* above an understory of *Rosa sp., Salix sp.,* and *Ledum decumbens.* The groundcover is dominantly *Vaccinium vitis-idaea, v. uliginosum,* with various mosses and lichens.

Soil Structure: The soil has an undecomposed leaf mat (LF) 8 cm thick overlying a 3 cm thick largely decomposed moder H layer. Very fine, fine and medium roots are abundant. The organic layer is underlain by a weak mull or mull-like moder Ah horizon 3 cm thick, dark brown (7.5YR3/2, m) in color, silty clay loam in texture and with friable fine to medium granular structure. A 12 cm thick Bm horizon lies below. The soil is moderately acidic (pH 4.5 - 5.2) with 12.2 percent organic matter in the Ah. (For a complete description see Brewer and Pawluk, 1975).

Classification: Brunisolic Turbic Cryosol.

Microstructure of Surface Layer: The lower leaf mat is primarily humi-phytogranic grading to ortho-phyto-humigranic in the H layer (Fig. 3a). Humigranic units are variable in shape and 50-200 μm in size. Fungal hyphae are abundant. Some large (850 μm) humigranic units are also present (Fig. 3b). The Ah horizon largely comprises a mullgranic fabric that grades to a matrigranoidic fabric with depth (Fig. 3c). Minor amounts of humigranic and phytogranic units and zones of mullgranoidic fabric are also evident. Basic fabric units are 50-90 μm in size although some units of 180-240 μm size are also present (Fig. 3d). Many aggrotubules comprising units of the same size and composition are present (Fig. 3e).

4. Boreal Forest Region

Location: Breton, Alberta

Landform: a) Undulating ground moraine.
b) Well drained soil adjacent to stream channel.

Vegetation: Canopy of *Populus tremuloides* and *Picea glauca* with groundcover comprising a mixture of various mosses, lichens and grasses.

Soil Structure: The surface organic layer comprises an undecomposed leaf litter (L) 1 cm thick underlain by a loose to matted semi-decomposed (F) layer 4 cm thick and a well decomposed matted humus (H) layer 1.5 cm thick. Acidity ranges from pH 5 to 6. Very fine and fine roots are plentiful and fungal hyphae are abundant. An Aeh forms the transition to a platy grayish brown (10YR5/2, m) eluviated Ae horizon. (For a complete description see Howitt and Pawluk, 1984).

Classification: Orthic Gray Luvisol.

Microstructure of Surface Layer: The F layer is dominantly phyto-humigranic fabric with partially decomposed plant fragments and humigranic units of variable size (Fig. 4a). Orthogranic f-members are rare to few. The H layer has a few mullgranic units and orthogranic units are more prominent as well. Phytogranic units diminish in importance. Fungal hyphae dominate throughout (Fig. 4b). Fabric units are of variable size (35 μm–1.2 mm) but show strong bimodal size distribution with dominance in the 90-125 μm size range and much fewer in the 600-750 μm size range (Figs. 4c and 4d). All units are largely of the humigranic type but develop a weak mull character near the lower boundary. There is a sharp separation to the underlying Aeh horizon which has a weakly banded mull-matrigranoidic vughy porphyric fabric type. Fine humigranic units occur only in the aggrotubules. Small humigranic units are also frequently observed in decomposing plant tissue (Fig. 4e) within all layers.

5. Transition Aspen Parkland Boreal Forest Region

Location:	Ellerslie, Alberta.
Landform:	a) Glacial Lake Edmonton Plain. b) Imperfectly drained site.
Vegetation:	Open stand of *Populus balsamifera* and *P. tremuloides* with a well developed shrub layer of *Cornus stolonifera, Rosa sp., Symphoricarpos albus* and minor admixtures of other shrubs. The herb layer comprises *Rubus pubescens, Mitella nuda, Mertensia paniculata, Cornus canadensis* along with a wide variety of other plants.
Soil Structure:	The surface layer comprises organic horizons 18 cm thick that are characteristic of the moder humus type. The upper partially decomposed litter (LF) is made up largely of aspen leaves. This layer grades into a dark red brown (5YR2/2, m) well decomposed loose, fluffy humus, below. The leaf litter has a near neutral pH and abundant roots of varying size. The organic layer is underlain by a mull-like Ah approximately 35 cm thick. The Ah is black (10YR2/1, m) silty clay in texture, and strong granular in structure. The soil is quite firm and also contains an abundance of roots. Weak mottling is evident in the underlying B horizon. (For a complete description see Sanborn and Pawluk, 1983).
Classification:	Gleyed Black Chernozemic.
Microstructure of Surface Layer:	The F layer has mull-humiphytogranic fabric comprising comminuted plant fragments and an abundance of humigranic units ranging in size from 35 μm to 950 μm. Units of 45 μm size dominate but units of 250-950 μm size (Fig. 5a) are also common. Large (400-600 μm) mullgranic units are concentrated in horizonal zones that resemble mull-like moder (Fig. 5b). The transition to the H layer shows a decrease in phytogranic units and stronger coalescence of units of 45 μm size to form a humigranoidic component. The H layer is characterized by humigranoidic fabric of coalesced units dominantly 25-40 μm and commonly 120-180 μm in size (Figs. 5c and 5d). Phytogranic and orthogranic components are relatively few. The fabric grades into a humi-mullgranoidic weakly banded fabric in the upper Ah comprising moderately well accommodated, partially fused granic units of variable size (Fig. 5e). Mullgranic fabric is better developed at a depth of 3 cm but gives way to mullgranoidic porphyric fabric with depth. Dominance of larger mullgranic units generally increases with depth but size of units remains quite variable.

6. Parkland Region

Location: Hay Lakes, Alberta
Landform: a) Undulating ground moraine.
b) Well drained soil on upper knoll.
Vegetation: Open stand of *Populus tremuloides* with a dense ground cover of grasses *Festuca stipa, Koelaria* and *Poa*. A wide variety of shrubs and forbes with *Rosa* dominating are also evident.
Soil Structure: The near neutral (pH 6.9) surface layer is a well developed black (10YR2/1, m) mull Ah horizon approximately 75 cm thick. The soil is loamy texture (22 percent clay), friable and strong granular. Organic matter content is 9.2 percent. The underlying Bm horizon contains numerous krotovinas and earthworm channels. (For more detailed description see Dudas and Pawluk, 1969).
Classification: Orthic Black Chernozem.
Microstructure of Surface Layer: Fabric of the Ah horizon is dominantly humi-mullgranic (Fig. 6a) with phytogranic units more prominent near the surface and with some orthogranic units throughout. Humigranic units are small in size (30-60 μm) while mullgranic units vary from 250 μm to 2 mm in size (Fig. 6b and 6c). There are occasional larger matrigranic units as well.

7. Alpine Region

Location: Sunshine Basin, Banff National Park, Alberta
Landform: a) Saddle adjacent to ridge, comprising colluvium/sandstone
b) Moderately well drained site on rise of land.
Vegetation: *Phyllodece glanderliflora* and *Antennaria lanata* plant communities comprising a variety of alpine grasses and forbes.
Soil Structure: The upper layer is a very dark brown (10YR3/2, m) moder grading to mull-like moder Ah horizon 11 cm thick, with silt loam texture and very friable weak fine granular to amorphous structure. Very fine and fine roots are abundant. The soil is moderately acidic (pH 4.8) with approximately 18.9 percent organic matter content. The horizon is underlain by a transition to the Bm. (For full description see Pawluk and Brewer, 1975c).
Classification: Orthic Sombric Brunisol.
Microstructure of Surface Layer: The moder humus layer has a humi-phytogranic fabric that grades to phyto-humigranic fabric below. Humigranic units have a size mode ranging from 20-180 μm (Fig. 7a). A few units of 550 μm size are also evident (Fig. 7b). The humus layer is underlain by an organic-rich Ah horizon that has humi-phyto-ortho-mullgranic fabric. The mullgranic units range in size from 20-400 μm (Fig. 7c) and show only weak organo clay complexing. There is a dominance of mullgranic units in the size range of 90-250 μm (Fig. 7d) in the upper zone but becomes better graded with depth. Glass shards, phytoliths and diatoms are common.

8. Intermontane Prairie Region

Location:	Lac du Bois (above Kamloops) British Columbia.
Landform:	a) Morainal drumlin. b) Well drained.
Vegetation:	Middle grassland comprising *Agropyron spicatum, Koeleria macranthe, Astragalus miser* along with other grassland species.
Soil Structure:	The surface is a very dark gray to black (10YR3/1[d]-2/1[m]) mull-like moder loam with weak fine granular to amorphous structure and very friable consistence (a turf-like feel). This layer is underlain by a Bm horizon. (For a complete description of site see McLean, A. 1982).
Classification:	Orthic Dark Brown Chernozem.
Microstructure of Surface Layer:	The fabric of the Ah is dominantly ortho-humigranic and granoidic with a minor chlamydic component (Fig. 8a). Humigranic units have a strong modal size in the 25 μm range (Fig. 8b) but few larger units 90-200 μm size and very few units of 450-600 μm size are also present (Fig. 8c). Very few phytogranic units are also found. Mullgranic units are notably absent although under high magnification humigranic units appear to have a weak mull-like character.

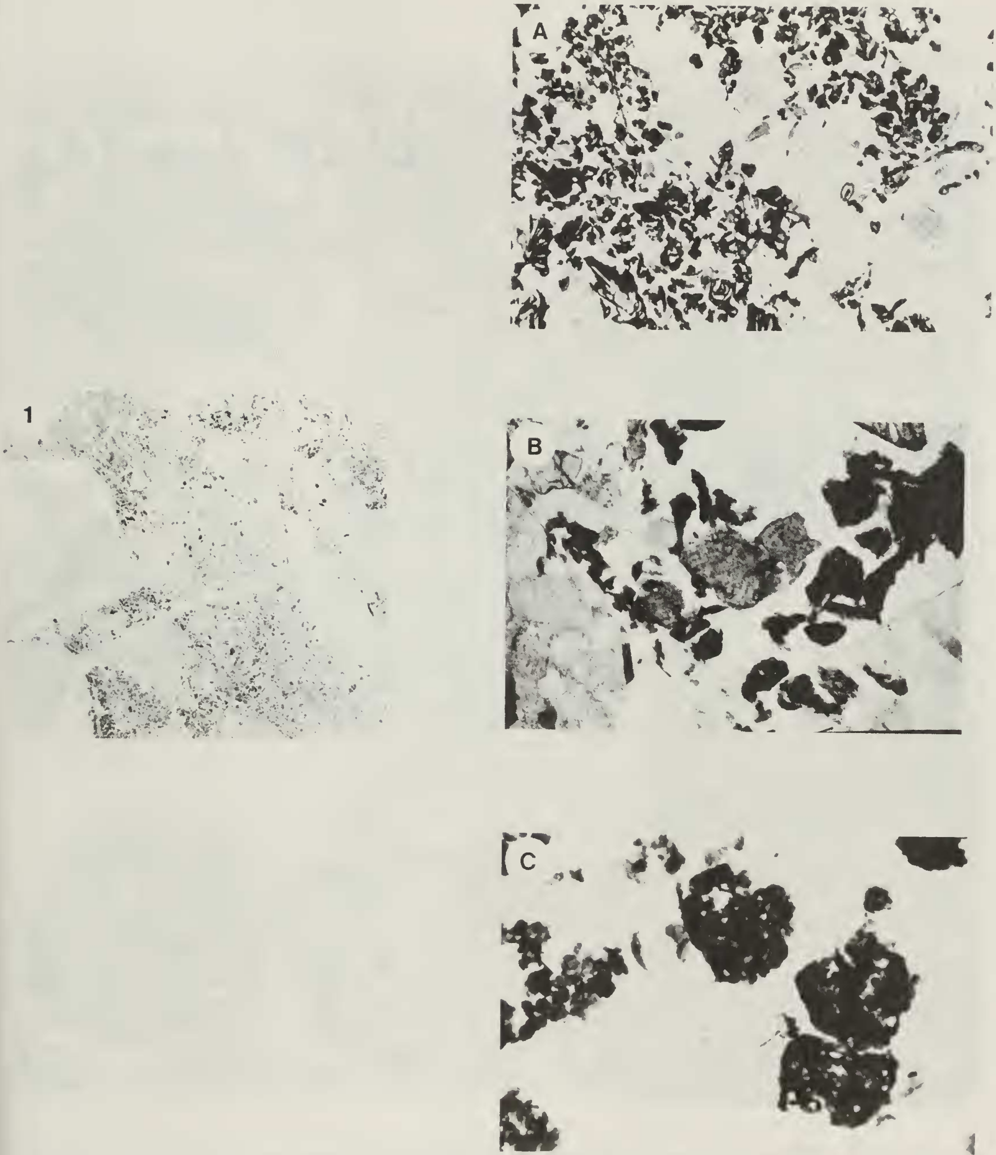

Fig. 1. Fabrics of moder humus from an Orthic Static Brunisol, Devon Island, Northwest Territories, Canada. – (a). Ortho-humigranic fabric (x30m); largely fecal pellets of microarthropods. (b). Humigranic units comprising fecal pellets 20-80 μm size (x150m) likely from collembolans and/or enchytraeids. (c). Loosely bound humigranic units 200 μm in size; probably enchytraeid cast (150xm).

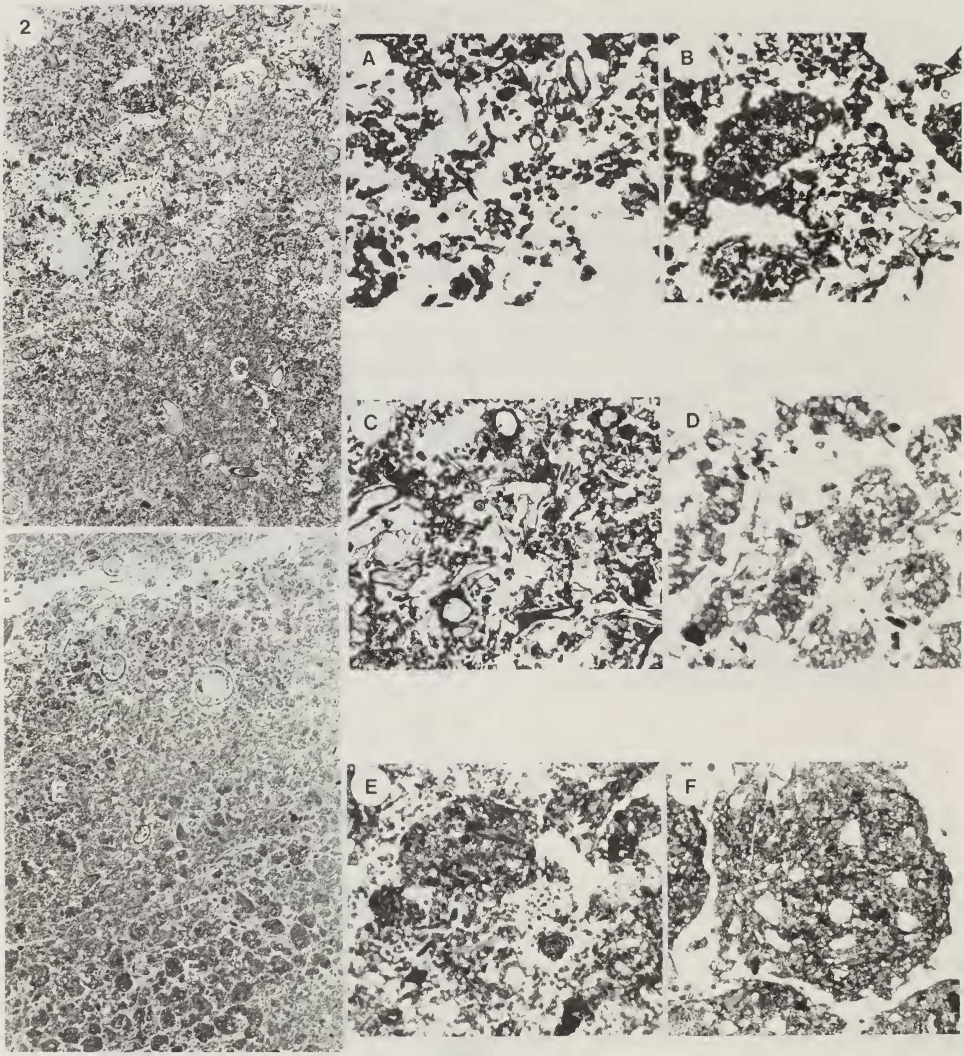

Fig. 2. Fabrics from the humus-rich layer of Brunisolic Turbic Cryosol, Tuktoyaktuk, Northwest Territories, Canada.– (a). Ortho-phyto-humigranic fabric (x30m); humigranic units show strong modal distribution of 50 μm and appear to be largely droppings of collembolans and enchytraeids. (b). Large fecal pellets (400-600 μm) (x30m) of dipteraous larvae and/or diplopods. (c). Phyto-mull-humigranoidic fabric (x30m); dominance of fecal material 90-100 μm in size comprising humus and mineral constituents, believed to be droppings of collembolans. (d). Larger mullgranic units (400-600 μm) in the A(B) horizon (x30m). (e). Smaller mullgranic units (40-120 μm) associated with larger units in the A(B) horizon (x30m), probably fecal pellets of collembolans and/or enchytraeids. (f). Large mull-matrigranic units (1-2 mm) (x30m); possibly fecal pellets but more likely formed through frost processes.

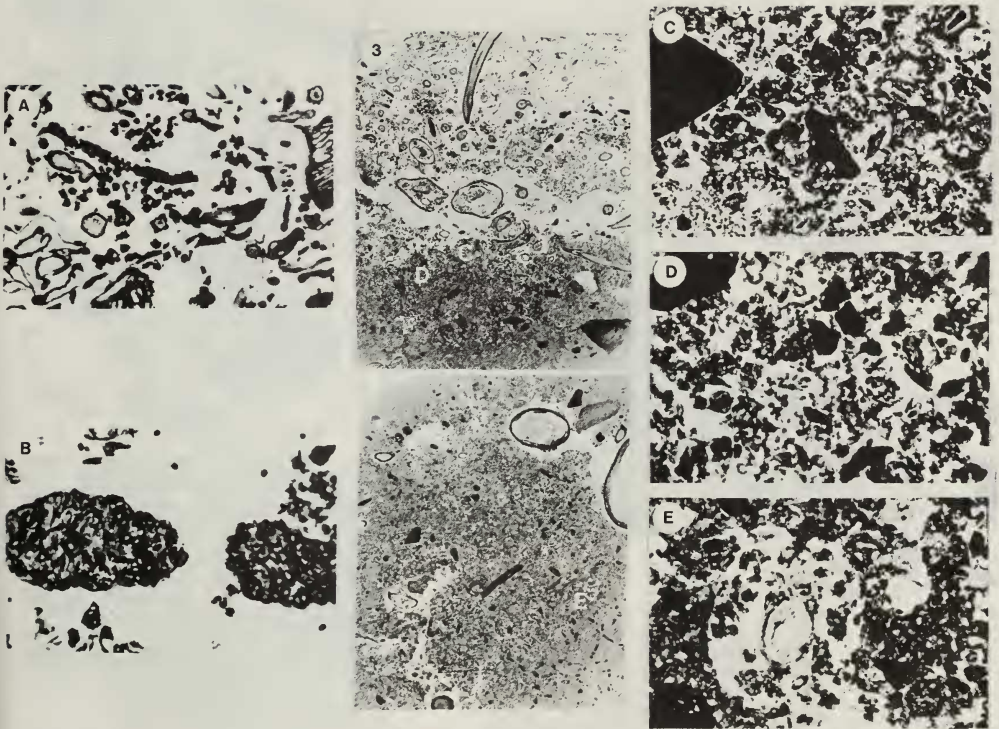

Fig. 3. Fabrics from the humus-rich layer of Brunisolic Turbic Cryosol, Inuvik, Northwest Territories, Canada.– (a). Ortho-phyto-humigranic fabric of the H layer (x30m). Majority of humigranic units are 50 μm in size and are likely fecal pellets of collembolans; larger casts of 90-120 μm size are likely those of enchytraeids. (b). Large fecal pellets (850 μm) of humic material (x30m) likely droppings of dipterous larvae. (c). Mullgranoidic fabric of the Ah horizon (x30m). Basic units are 50-90 μm size with some units 180-240 μm size also evident. The smaller units are likely fecal pellets of enchytraeids and/or collembolans. (d). Same as (c) (x50m). (e). Aggrotubule with fecal pellets (x50m).

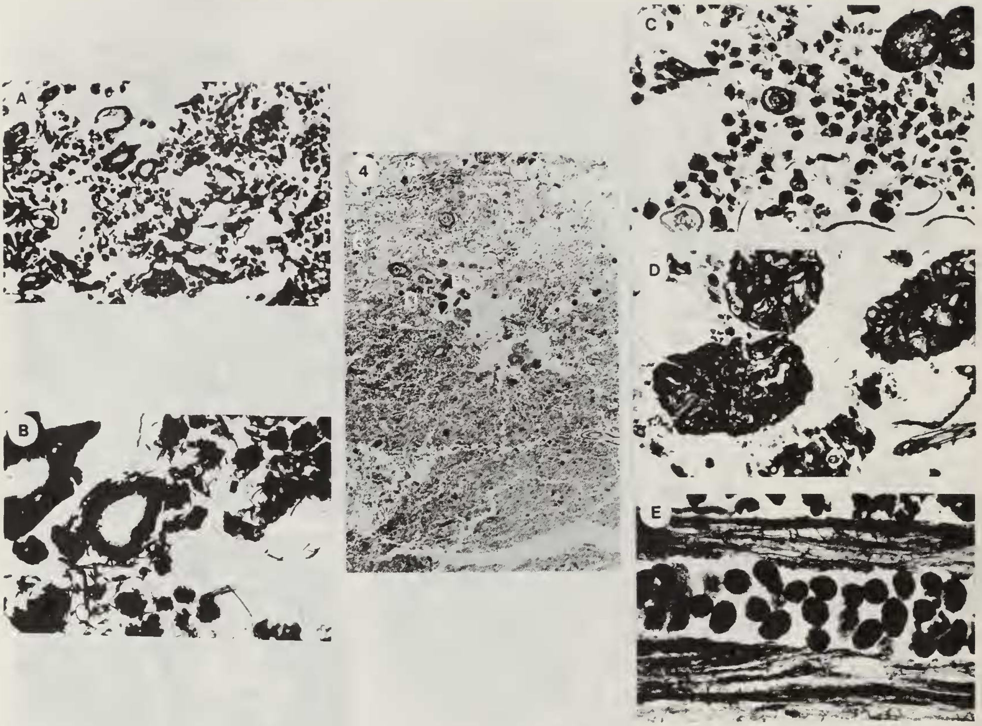

Fig. 4. Fabrics from the organic layer of an Orthic Gray Luvisol, Breton, Alberta, Canada.– (a). Phyto-humigranic fabric of the F layer (x30m). Fecal pellets are dominantly 50 μm size possibly from collembolans. (b). Abundant fungal hyphae intimately associated with fecal pellets (50-60 μm) and plant fragments (x150m). (c). Zone of humic fabric with a dominance of fecal pellets 90-125 μm size (x30m). Regularity in the shape of the units suggests casts of collembolans although other animals cannot be discounted. (d). Zone of humic fabric with a dominance of fecal pellets 600-750 μm size (x30m). Their presence likely reflects the activity of dipterous larvae and/or small earthworms. (e). Fecal pellets (25 μm) of acarines in decomposing plant tissue (x150m).

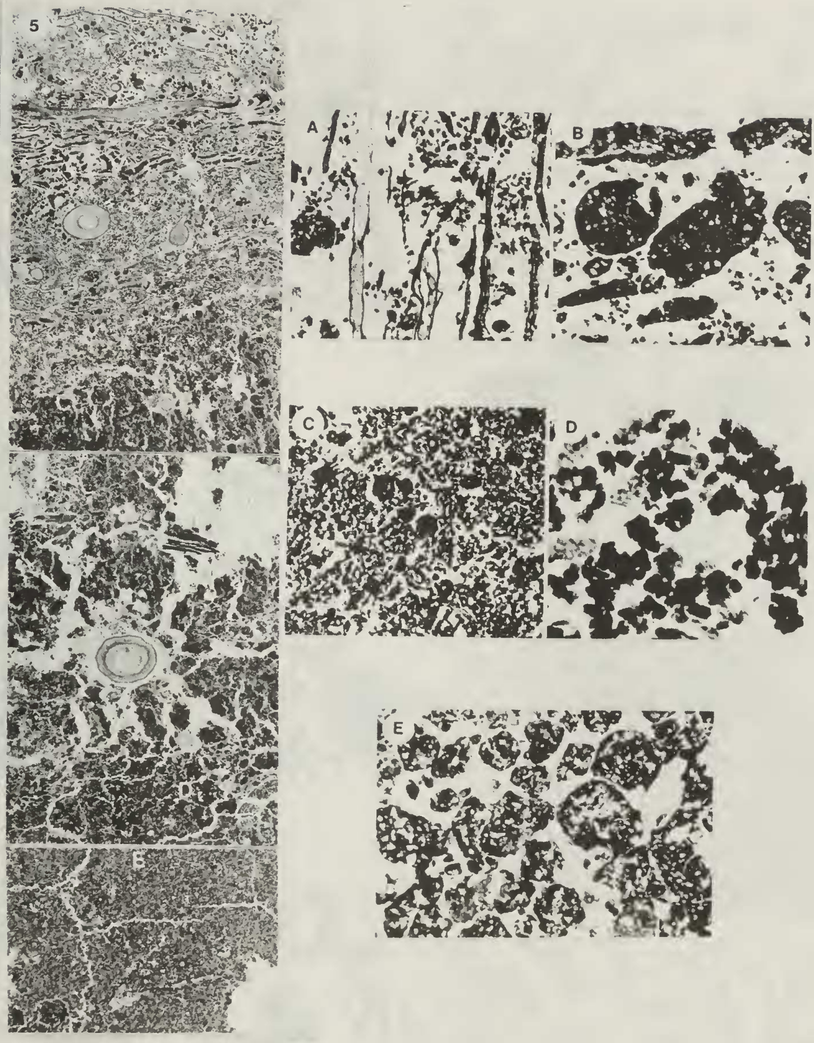

Fig. 5. Fabrics from humus-rich layers of Gleyed Black Chernozem, Ellerslie, Alberta, Canada.– (a). Mull-humi-phytogranic fabric of the F layer (x30m). Small humigranic units (35 μm) are fecal pellets of microarthropods, the larger units (350-400 μm) are likely fecal pellets of diplopods. (b). Mullgranic units (400-600 μm) in the upper H layer are likely diplopod casts (x30m). (c). Humigranoidic fabric of the lower H layer (x30m). Units of fabric comprise entire and decomposing small fecal pellets (25-40 μm) of small arthropods and larger fecal pellets (120-180 μm) possibly of isopods and/or enchytraeids. (d). Discrete and decomposing fecal pellets of collembolans and/or enchytraeids in c) under high magnification (units 25-40 μm size). (x150m). (e). Humi-mullgranoidic fabric of the Ah with units dominantly 450-500 μm size (x30m). Units are porous and appear to comprise smaller fecal pellets reorganized through frost processes.

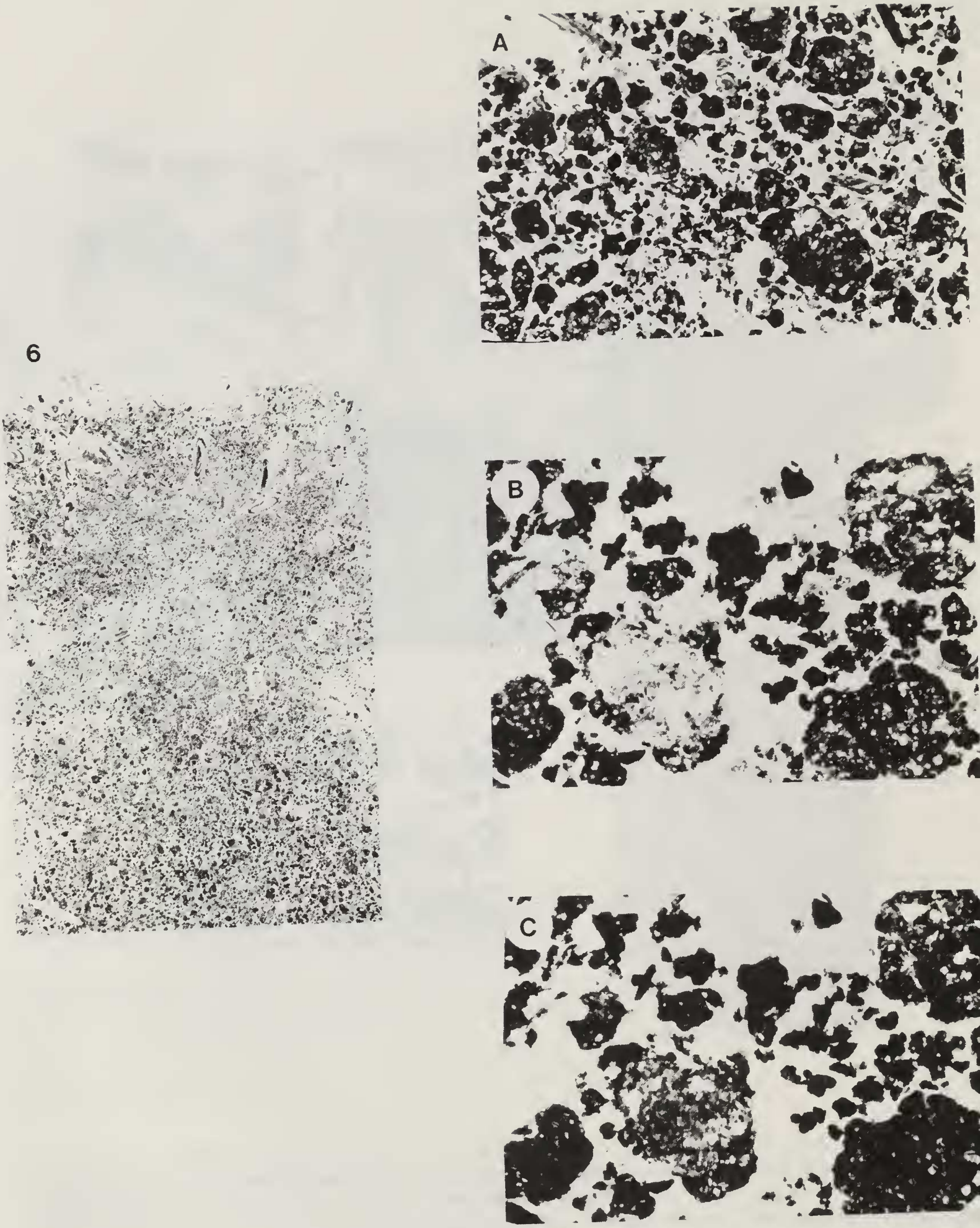

Fig. 6. Fabrics of Ah horizon from an Orthic Black Chernozem, Hay Lakes, Alberta, Canada.– (a). Humi-mullgranic fabric from the Ah (x30m). Fecal pellets vary in size from 30 μm to 400 μm. Smaller units are humigranic. (b) Small humigranic and larger mullgranic units of fabric from the Ah (x50m) ppl. Note uneven distribution of clay and humus in plasma. (c) Same as (b) in plain light.

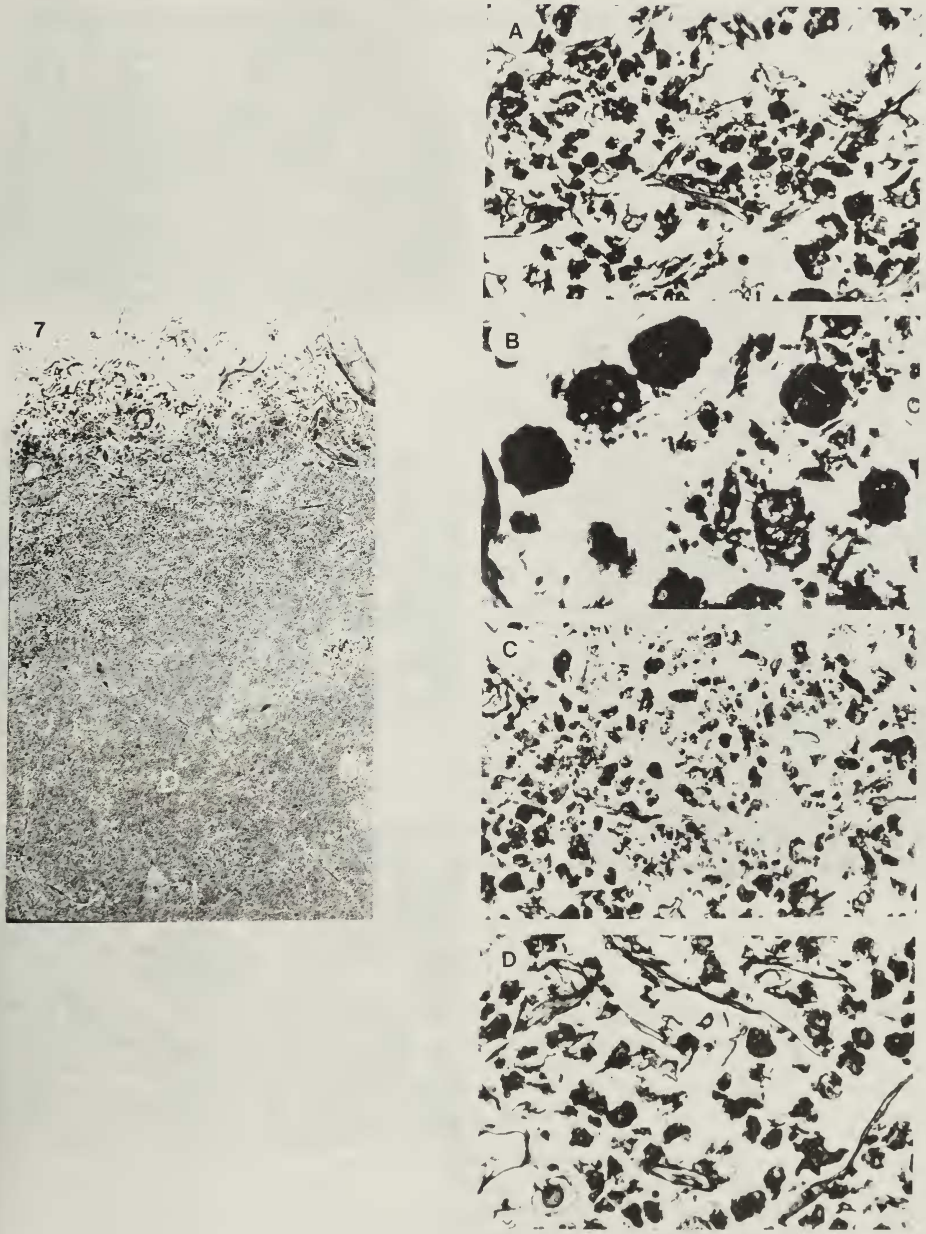

Fig. 7. Fabrics of humus-rich layers of Orthic Sombric Brunisol, Sunshine Basin, Alberta, Canada.– (a). Phyto-humigranic fabric in moder humus layer (x30m). Humus fecal pellets range in size from 20-180 μm and probably reflect activity of collembolans and enchytraeids. (b). Fecal pellets comprising humic material and silt grains in same layer as a). Large units (450-550 μm) are probably casts of Diplopoda (x30m). (c). Humi-ortho-mullgranic fabric in Ah. Mullgranic units range from 20-250 μm (x30m). (d). Mullgranic units in Ah 90-250 μm in size (x30m) possibly collembolans and/or enchytraeid fecal pellets.

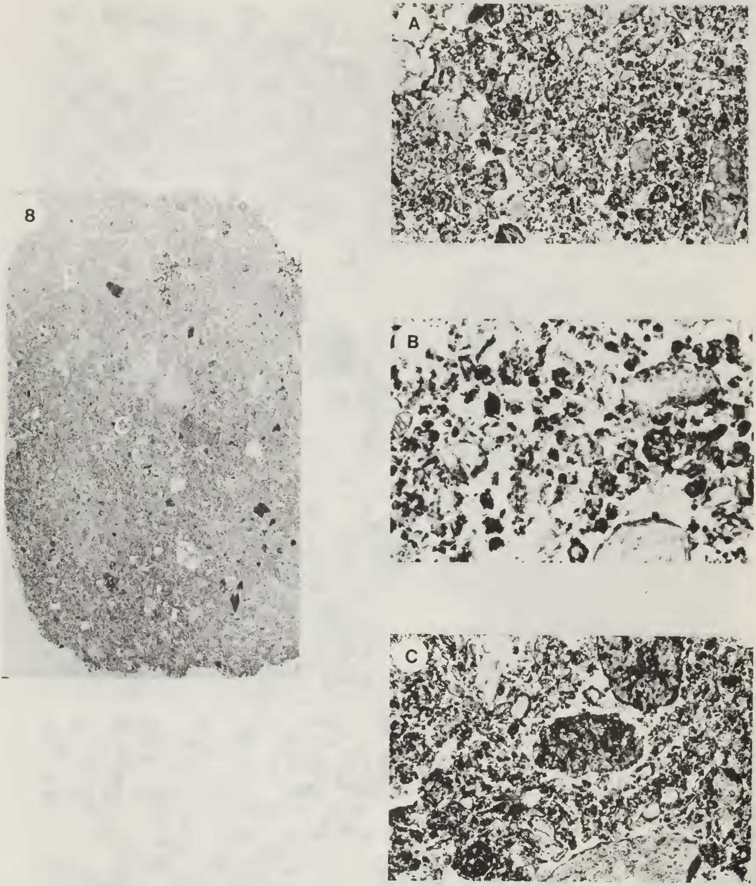

Fig. 8. Fabrics of Ah horizons of Orthic Dark Brown Chernozem, Lac du Bois, British Columbia, Canada.– (a). Ortho-humigranic fabric with Chlamydic component in Ah (x30m). (b). Humigranic units dominantly 25 μm size (x150m) probably fecal pellets of microarthropods. (c). Fecal pellets 450-600 μm size probably of diplopods (x30m).